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THE DIRECTION OF THE EVOLUTION OF SCIENCE AND THE PLACE OF SIGMA XI IN SUCH EVOLUTION[1]

I RECENTLY read Professor Conklin's book "The Direction of Human Evolution" and his thesis so impressed me that I wish to apply his methods of analysis to-night to the subject of the evolution of science.

Dr. Conklin believes that the direction which human evolution will travel can be more or less accurately predicted by studying the path that evolution has already traveled and analyzing such knowledge so as to arrive at the basic laws which have governed the evolution of the past and presumably will govern the evolution of the future. Let us therefore apply his methods to the general field of science and view in retrospect the past and attempt to postulate the future.

When science actually began will probably never be known. It probably began in a rudimentary form soon after man evolved into a more or less intelligent being, for the discovery of the art of making fire was a scientific discovery of exceedingly great value to the human race. The recording of scientific observations probably goes back nearly to the beginning of written history, and when one contemplates the contributions of some of the earlier workers to science, one wonders whether or not we ourselves have actually progressed very far. We are accustomed to ascribe to Copernicus and his school the belief that the earth was not flat but a sphere and that it revolved about the sun and yet 1800 years before Copernicus was born Heraclites of Pontus (about 375 B.C.) stated that the earth revolved on its axis from west to east once in twenty-four hours and that the earth, Mercury and Venus revolved about the sun. Aristarchus of Lamos (about 270 B.C.) found

[1] Presidential address, University of Minnesota chapter of Sigma Xi, June 13, 1921.

that the poles were not fixed but oscillated in a circle and he fixed the diameter of that circle and the period of revolution so accurately that only the most modern instruments can detect the small amount that he was in error.

Perhaps the most noteworthy of the ancient scientists was Hipparchus of Rhodes (about 146 B.C.). He discovered the procession of the equinoxes due to a slight progressive shifting in the equinoxial points where the celestial equator and the ecliptic meet, and predicted, with almost modern exactness, the period in which the plane of the earth's excentric orbit would shift from maximum to maximum. He determined the length of the year within six minutes. He established the Tropics of Capricorn and Cancer within twenty-four miles of their present location and in order to do this he invented the science of trigonometry. Surely many a modern worker would have rested on his laurels after such a feat. Nevertheless he was not content to rest here but prepared a star catalogue of more than 1,000 stars, his list of constellations being the basis of the one used at present. One can but wonder what such a genius would have accomplished had he had modern instruments and libraries.

The few old manuscripts that are extant tell a wonderous story of science under Egypt and early Greece and we can only wonder how many more of the modern "discoveries" were known to the ancients. Conklin believes that human evolution reached its crest in the Golden Age of Greece, for he states that Greece produced more great geniuses in that period of 200 years than have ever been produced in a like period before or since. He believes that eugenically the Greeks at that time were a superior race and that inbreeding with their captive races and later with their conquerors has lowered, as it inevitably would, their potentialities for genius.

But modern science is not derived from the knowledge of the ancients. At no time in the ancient order of things was education the prerogative of every man. Knowledge was rather held to be the property of a secluded few and was passed on from the master to a few chosen disciples, so that with the advent of the Dark Ages the light of science soon died out until only a few sparks were left here and there. Meanwhile those nations which had stood foremost in the ancient learning became the vassals of other and less enlightened powers. The Alexandrian Museum, the repository of all the ancient lore, had been burned by the Turks, and many of the surviving manuscripts had been destroyed by the order of the Church. Consequently with the revival of learning men did not turn to existing knowledge as found in written form, but they began to construct anew the story of the earth and its natural wonders. We have thus two cycles of evolution from which to chose in drawing our analogy as to what the future may hold. Because of the fact that we know only fragments of the earlier story, it seems best to ignore it entirely and to draw our conclusions as to the future from the evolution of science since the Dark Ages.

One can not but wonder, however, whether such a catastrophe as the Dark Ages will ever again occur—whether our present knowledge will again be lost in fanaticism and bigotry. We hope and trust that such can never be, but when we think of what has happened in Russia within the past five years, when we read in SCIENCE of only last week how the foremost scientists of Russia are dying of hunger, cold and disease, how all scientific progress in that great nation has stopped, we can not be assured that another dark age will never come—we can only hope the tide will not sweep over the rest of the world. Had any one prophesied the present condition of Russia fifteen years ago he would have been laughed at as a dreamer, and we must remember that the Dark Ages of 400–1000 A. D. extended over a territory measured in square miles scarcely greater than that covered by the present scientific blanket of 1921. Only the wide expanse in which science holds sway at present has prevented a second "Dark Age."

The Revival of Learning following the Dark Ages was a slow and tedious process. The

search for the Philosopher's Stone and the Elixir of life retarded rather than furthered its progress, for the element of secrecy was all important upon such a quest, and science can not forge ahead under such a handicap. The scientist who prosecutes his studies from a selfish motive may personally succeed, but he can never hope to be listed among those names which are revered in later generations. When we think of the illustrious names which stand out in scientific history there is a remarkable unanimity in the fact that almost without exception they were pushing forward the field of knowledge purely for the joy that it gave them and not for fame or pecuniary reward.

The first great class of men to whom science owes an incalculable debt are the "naturalists"—men like Linnæus, Darwin, the Agassizes, Humboldt, who were at home in almost any field, and who have recorded observations on almost every subject. Dr. Woodward, former president of the Carnegie Institution of Washington, once said that science must pass through five stages:

1. The bug hunting, rock naming stage, *i.e.*, the observational stage.
2. The classification stage in which existing knowledge is put in order.
3. The experimental stage in which new conditions are imposed and new facts gained.
4. The theorizing stage in which the results of observation and experimentation are drawn together in the form of laws, and lastly
5. The mathematical stage—the expression of these laws of nature in mathematical formulæ.

The naturalists belonged largely to the first and second of these stages. To them we owe a considerable part of our present knowledge of the nature of the earth and its flora and fauna.

We can all appreciate the relative simplicity of the science of their time if we contemplate what they were able to do. Is there any one among you who would be willing to act as geologist, mineralogist, botanist, zoologist, meteorologist, anthropologist, archæologist, etc., on an expedition into an unknown land and who would guarantee that on the completion of the expedition you would undertake to write up the scientific results in such a form that the work would be a classic in all respects? I dare say not, and yet that was what the naturalists did. Science was in its infancy—almost every observation was new—and a genius could be authority in many fields. The day of the naturalist, in the sense that I am using it, has passed. Science is too complex.

We then pass to the experimental stage. Only a few years ago this was a new field of work. We began to tear down, to dissect, to study, to build up, and how much we have accomplished. In 1828 Wöhler prepared urea, the first "organic" compound to be artificially synthesized. The "organic" compounds were supposed to be created only by "organized" life. Since that time at least 150,000 organic compounds have been synthesized including the alizarine, which wiped out the cultivation of the madder in France, indigo, which threatened for a time to bring starvation to thousands in India because of the destruction of the indigo plantations, and even the "purple of Tyre," secreted by a mollusc, and which dyed the royal robes of ancient Asia Minor, has yielded its secret to the chemist, 1.5 grams of 6.6 di brom indigo being obtained from 12,000 shellfish. It can now be purchased in pound lots from chemical firms.

During this period of evolution science became more complex. The field of knowledge in which one could become proficient became more narrow. We have scientists who were authority only on chemistry, or on zoology, or on physics, or on botany, etc., but each had a very wide and complete knowledge of his chosen branch. To be sure when a professor was appointed to a chair in a university during this period he might be expected to lecture in a related or nearly related field. For example, the chemist might be expected to lecture on geology, mineralogy or crystal-

lography, the botanist to lecture on zoology, and the mathematician on physics or astronomy. Nevertheless specialization was beginning, science was growing.

To some of the younger members present, this period may seem to be long passed. Just as an illustration I may say that I received my first lectures in chemistry, geology, mineralogy and crystallography from one professor, and my physics and mathematics from another.

The next period succeeded in rapid succession—a professor was expected to be expert in only *one* science, but a chemist must know inorganic chemistry, organic chemistry, physical chemistry, analytical chemistry, assaying, etc., and what is more he was expected to teach all of these branches with equal facility and authority. The botanist must know morphology, taxonomy, cytology, bacteriology, physiology, etc., not only of one group of plants, but of all groups and teach and direct research workers in all branches, and so on for the other sciences. This period is rapidly passing and will soon be gone.

To-day we have narrowed our field. The mass of facts and theories in any branch of science has accumulated so rapidly, the scientific workers have so multiplied, that in a few years we will be fortunate if we can claim *authority* in a *narrow* branch of a *special* field. The evolution of the scientific journals is proof of this evolution. We have colloid journals for the colloid chemist, physical-chemical journals for the physical chemist, organic-chemical journals for the organic chemist, food journals for the food chemist, biological journals for the biological chemist, cereal-chemical journals for the cereal chemist, and so on *ad infinitum*. There is no end—there can be no end if science is to continue its evolution. The same situation holds for the botanist. They have their physiological and ecological journals. The physicist has those journals which specialize in radio activity, electricity, etc., and in the medical field there is possibly an even greater range of specialization than in any other.

Such is the situation to-day—where is it to end? It is not to end! As scientific workers increase in number, as the mass of scientific knowledge increases while the mind of man remains limited in the amount of information which it can properly assimilate, we must more and more become a group of specialists centering our intensive study upon a narrower and narrower field. The specialization that we have seen in medical science is only a special instance of the future of all science. The university of the future will have a professor of radium, a professor of the structure of the atom, and another professor of the α particle or the atomic nucleus,—yes, even a professor of the electron.

The time of the naturalist has passed, the time of the broad scientist is passing, the day of the specialist is dawning—has, in some instances, actually arrived. Science is sweeping forward with tremendous strides, and I do not envy the young candidate for the Ph.D. degree who 100 years hence will be required to search through the literature and compile a monographic history of the problem which he presents as his dissertation.

So much for my vision of the future. How is mankind to utilize to its best advantage the knowledge of these specialists fifty or one hundred years hence? How are the great problems of the world to be solved by men who can see only isolated trees in the great forests of nature? Probably the answer is cooperation. A problem will be attacked not by one worker but by ten, twenty or one hundred workers, who will pool their knowledge, their individuality, their selfishness and who will all work together for the glory of science and the good of mankind. Dr. Crocker, the director of the new Thompson Institute for Plant Research, recently said to me that he believed the day was not far distant when five or ten men would be permitted to present a single dissertation for the Doctor's degree, a masterpiece of research worked out in cooperation by the group, and into which each had put the best of his effort and manipulative skill. He has already so far convinced the graduate school of the University of Chicago that in one or two instances

one dissertation has been presented by two men working together. The big problems of biology are already too large for individual attack. We must have biologists, chemists, geneticists, statisticians, bacteriologists, pathologists—all working together to adequately solve them—and how much more rapidly science would advance if we could secure such cooperation! A specialist for every phase rather than a "Jack of all sciences" attacking the problem alone. And what part is Sigma Xi to play in it all? Sigma Xi if it is to play any part must yield to the processes of evolution or be passed in the race.

Sigma Xi was founded because scientists felt the need for a bond to draw them together and to propagandize in favor of science in the universities. In that day Latin, Greek, the languages and literature, history and philosophy, were the recognized collegiate courses. Science had not come into its own. What part Sigma Xi played in the establishment of science courses will probably never be accurately determined, but the day is already past when science needs any assistance in establishing its proper place in a university curriculum. Science has arrived! And with the evolution of science I am afraid Sigma Xi is being left behind. We no longer get together in scientific meetings to discuss the individual researches of science workers. Science has become too specialized. Many a university now has its chemical society, its pathological society, its society of clinical medicine, its physical society, its mathematical society, its botanical society, its physiological society, etc., etc. To be sure we call them seminars in many instances, but the result is the same. There are likewise new "Honorary" societies being formed, such as Phi Lambda Upsilon for chemistry, which have a special attraction for a special group. Where then is Sigma Xi's place in this new order of things?

If Sigma Xi is to live to fulfill the hopes of its founders it must meet the challenge of the new order with a definite mission. I believe that there is a place for Sigma Xi in the new order. It was created to foster science—why should its new mission not be to coordinate science, to foster cooperation, to be the guiding hand in establishing an *esprit de corps* among science workers, to attract to the universities noted lecturers in special branches of science, especially those branches which are the weakest in the university in question, to assist in the securing of the formation of special scientific bodies within the university, especially the honorary scientific societies of the special groups? For after all, it is the *specialist*, not the scatterer, who brings fame to a university. In short, Sigma Xi should be the keystone of the scientific structure and should devote all of its energies to those means which will advance the special sciences and which will draw scientific workers into a union so that they may attack the great problems of the future.

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THE RELATION OF CHEMICAL TRAINING TO INDUSTRY[1]

THE relation of chemical science to education and industry is no new problem. During the last few years a quantity of opinion and advice has been offered to us and, as one result at least, the fact stands out that there is need of adjustment between educational institutions training scientific men and the industries which these men are to serve.

Looking back historically, it seems evident that the present misunderstanding between the two great parties concerned arose because of the different points of view as to how (*a*) the results of scientific discovery, and (*b*) the young graduates in science prepared at our colleges and universities could best be utilized in industry. The teachers of science are often unfamiliar with the needs of industry in regard to the nature of the problems to be solved and in regard to the kinds of scientists needed in our highly organized commercial enterprises. On the other hand, manufacturers are often at a loss as to how

[1] President's address before the Kentucky Academy of Science, Lexington, May 14, 1921.